EFFECT OF DIMENSIONAL PARAMETERS ON WARPAGE OF INJECTION-MOLDED PLASTIC PART USING RESPONSE SURFACE METHODOLOGY

MOHD NASRI B MD SALIM

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UNIVERSITI MALAYSIA PAHANG

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STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature
Name: Mohd Nasri Md Salim
ID Number: ME 06050
Date: 24/11/2009

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ABSTRACT

This thesis discusses the effect of dimensional parameters on warpage of injection-molded plastic part using response surface method. The objectives of this thesis are to investigate the effect of dimensional parameter on warpage, to develop prediction first and second mathematical model for warpage of plastic part using response surface method. A thin plastic part model is used in the analysis. To achieve minimum warpage, optimum process condition dimensional parameters are determined. X dimension, Y dimension and Z dimension are used as variables. The most important input parameter in this experiment is Z dimension (wall thickness) which is affecting the warpage of the plastic part. The others input also must be considered. Use the different value of X dimension, Y dimension and Z dimension to determine different value of warpage. The design of experiment that use in this experiment is three level full factorial designs. Finite element analysis using MoldFlow is done to determine experimental value of warpage. Response surface methodology is used to predict the warpage value based on finite element result and suitable predictive model is selected based on percentage of error comparison then optimization process using response surface method is done and the optimum dimensional parameters with minimum warpage value is obtained.

ABSTRAK

Tesis ini membincangkan kesan parameter dimensi pada warpage injeksi-bahagian plastik menggunakan kaedah permukaan respons. Objektif daripada tesis ini adalah untuk meneliti kesan daripada parameter pada warpage dimensi, untuk mengembangkan ramalan pertama dan kedua model matematik untuk warpage bahagian plastik menggunakan kaedah permukaan respons. Bahagian plastik tipis model yang digunakan dalam analisis. Untuk mencapai minimum warpage, kondisi muat yang optimum ditentukan parameter dimensi. Dimensi X, dimensi Y dan dimensi Z digunakan sebagai pembolehubah. Yang paling penting parameter masukan dalam percubaan ini adalah dimensi Z (ketebalan dinding) yang mempengaruhi warpage bahagian plastik. Masukan yang lain juga harus dipertimbangkan. Guna nilai yang berbeza dimensi X, Y dan Z dimensi dimensi untuk menentukan nilai yang berbeza warpage. Rancangan percubaan yang digunakan dalam percubaan ini adalah tiga peringkat rekabentuk faktorial lengkap. Analisis elemen hingga menggunakan MoldFlow dilakukan untuk menentukan nilai percubaan warpage. Permukaan respons metodologi yang digunakan untuk memprediksi nilai warpage berdasarkan keputusan elemen hingga dan model ramalan yang sesuai dipilih berdasarkan nisbah peratusan kesalahan maka proses pengoptimuman menggunakan kaedah respon permukaan dilakukan dan parameter dimensi yang optimum dengan nilai minimum yang diperolehi warpage.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

W	Warpage First RSM Model
W''	Warpage Second RSM Model
x	X dimension (mm)
y	Y dimension (mm)
z	Z dimension (mm)
β	Model Parameter

LIST OF ABBREVIATIONS

FE	Finite Element
RSM	Response Surface Method
MPI	MoldFlow Plastics Insight
CAD	Computer Aided Design
VS	Versus
ANN	Artificial Neural Network
GA	Genetic Algorithm

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

Injection molding operation is the most cost-effective and agile processing technology for manufacturing when it comes to high demand for the components on a mass scale. The procedure of injection molding is described, such as plastication, injection, packing, cooling, ejection and process part/part quality control applications. When the interior of cavity has become stable, the product is ejected from the mold. Defects of the products, such as warpage, shrinkage, sink marks, and residual stress, are caused by many factors during the production process. These defects influence the quality and accuracy of the products. Dimensional stability is an important factor for the minimum warpage of name card holder part. Reducing warpage is one of the top priorities to improve the quality of injection-molded parts. During production of plastic parts, the quality problems arise from dimensional ratio of the parts designed. Designs of dimensional process parameters are investigated from several aspects in the literature. Several researches have been conducted on the warpage of name card holder parts. However, very few of them are devoted to the optimization of such parts. In this study, an efficient optimization method by coupling finite element analysis, response surface methodology and genetic algorithm is introduced to minimize warpage of name card holder parts. The developed optimization method is applied to a name card holder part model. During the optimization process, finite element (FE) analyses of the part model base are conducted for combination of process parameters organized based on statistical full factorial experimental design. X dimension, Y dimension, and Z dimension are considered as process conditions dimensional parameters influencing warpage. Other parameters of effecting minimum warpage are taken into consideration as constant, such as mold temperature, melt temperature, injection time, injection pressure, etc. A predictive model for warpage in terms of the critical process parameters is then created using response surface methodology. Response surface model is coupled with an effective genetic algorithm to find the optimum process parameter values. The following sections explain in detail the generation of predictive models for minimum warpage (Babur Ozcelik & Tuncay Erzurumlu).

1.2 OBJECTIVE

The objectives of the project are:

1. To develop prediction first and second mathematical model for warpage of thin shell plastic part using response surface method
2. To investigate the effect of dimensional parameter on warpage of thin shell plastic part
3. To investigate the optimum dimension for the thin shell plastic part with minimum warpage

1.3 PROBLEM STATEMENT

The plastic industry today is one of the most important industries in the manufacturing world. Many manufacturers are focusing in developing plastics parts for most of things in our daily life. For example, this news, Forte nanocomposite nears 2nd application By Frank Esposito GALVESTON, TEXAS --Posted October 4, 2004 Noble Polymers is gaining ground with its Forte-brand nanocomposites, aiming to have its second commercial application as well as an extrusion grade on the market by mid-2005. Forte, a polypropylene-based nanocomposite, is used in the interior trim console of a vehicle that will hit the road in June, Noble business unit leader Tim Patterson said at Flexpo 2004, held Sept. 15-17 in Galveston. Patterson declined to identify the vehicle, citing confidentiality agreements, but the console is noteworthy in that it is not being molded by Cascade Engineering Inc., the Grand Rapids, Mich.-based injection molded that owns Noble. The first commercial nano- composite use for Noble - which operates about 80 million pounds of compounding capacity and employs 23 in Grand Rapids - was a seat back molded by Cascade in September 2003. Cascade currently consumes about 95 percent of Noble's compounding output - mainly soft, flexible thermoplastic olefins - but Noble eventually hopes to sell more of its product to outside customers, Patterson said. The seat back commercialized last year had used 30 percent glass-filled PP, but had warpage issues, Cascade materials engineering director Taher Abujoudeh said. Forte eliminated warpage while offering better aesthetics and lower cost, he said. Other nanocomposite projects in the works for Noble include office furniture - where it can replace 20 percent glass-filled PP - as well as heavy-truck exterior trim and speaker housing parts. The nanocomposite business started out small for Noble, with modest sales of about 700,000 pounds in its just-completed fiscal year. But the firm already has new sales on the books equaling that amount, Patterson said. To date, Noble's nanocomposite work has centered on injection molding grades. Its first extrusion grade is set to debut in June, Abujoudeh said. Cascade placed 30th in a recent Plastics News ranking of North American injection molders, with annual sales of $200 million (http://www.plasticsnews.com/headlines2.html?id=04100401403&q=warpage 24/3/09 Tuesday).

1.4 PROBLEM SOLVING

From this study of effect of dimensional parameter on warpage, the problem encounter due to warpage of plastics part can be solved. Then the losses caused by rejected part due to warpage can be solved. The study of warpage optimization is one of the solutions to the problem faced by plastics industry.

1.5 PROJECT SCOPE

1. Using Finite Element (FE) (Moldflow) to get experimental warpage value
2. Using warpage value from MoldFlow to predict warpage using Respond Surface Method (RSM)
3. Compare result of FE analysis with predicted result from RSM (choose parameter with smallest predicted warpage value)

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Injection molding is one of the most important polymer processing methods for producing plastic parts. Process parameters in addition to molding material and part design are major factors affecting the quality of plastic parts produced by injection molding. Quality of these parts is often associated with warpage. Effects of process parameters on non-uniform shrinkage leading to warpage are investigated from several aspects in literature. In this study, the effect of dimensional parameter values for name card holder in minimizing warpage is investigated. Best values of process parameters in this study are obtained by exploiting advantages of finite element (FE) software MoldFlow, statistical design of experiments, integrated response surface method and genetic algorithm. FE analyses of the name card holder are conducted for dimensional parameters designed based on statistical full factorial experimental design. A predictive model for warpage is then created using integrated response surface method exploiting FE analysis results.

2.2 DIMENSIONAL INTEGRITY

The configuration (shape and dimensions) of a molded part is intimately related to the thermo-mechanical history of the material used during the process cycle, the cavity geometry, and the physical properties (compressibility and thermal expansion coefficient) of the material. The configuration of the molded part can be divided into two main contributions: (a) the “as-molded” configuration and (b) changes in configuration over time. The as-molded configuration is determined by the state of the material in the mold cavity at the instant just prior to mold opening, the abrupt changes in pressure and stress upon injection, and the subsequent unconstrained cooling of the solid part to ambient temperature after injection from the mold. The final configuration of as-molded part is controlled by several distinct, though strongly coupled, factors, including the pressure and temperature histories in the mold cavity, cooling (thermal) stress, warpage, and shrinkage. Warpage relates to the distortion induced by the inhomogeneous shrinkage and relaxation of residual stress in the part once outside the mold, while shrinkage simply expresses the overall dimensional change as the unconstrained part cool down to ambient temperature. (Jehuda Greener & Reinhold wimberger-Friedl)

2.3 INJECTION MOLDING HISTORY

The injection molding has seen steady growth since its beginnings in the late 1800's. The technique has evolved from the production of combs and buttons to major consumer, industrial, medical, and aerospace products. In 1868, perhaps in response to a request by billiard ball maker Phelan and Collander, John Wesley Hyatt invented a way to make billiard balls by injecting celluloid into a mould. By 1872, John and his brother Isaiah Hyatt patented the injection molding machine. The machine was primitive yet it was quite suitable for their purposes. It contained a basic plunger to inject the plastic into a mould through a heated cylinder. Revolutionizing the plastics industry in 1946, James Hendry built the first screw injection molding machine with an auger design to replace Hyatt's plunger. The auger is placed inside the cylinder and mixes the injection material before pushing forward and injecting the material into the mould. Now day, almost all injection molding machines use this same technique. (http://www.plasticmoulding.ca/history.htm)

2.4 INJECTION MOLDING PROCESS PARAMETERS

Injection molding process have a few processing parameter. The processing parameter such as:

a) **Temperatures**

Typical temperature profiles are based on gradually increasing temperature during the compression phase with cooling at the nozzle.

b) **Injection**

A slow to moderate injection speed should be used if injection speed is too fast. The frictional heat can cause surface imperfections.

c) **Mold Temperature**

The recommend temperature for general molding for the mold is between 10°C to 40°C. However for certain grades and end applications a reduction below 10°C has been found to offer advantages with cycle time. When using temperatures below 10°C care must be taken to ensure cavities will consistently fill and no condensation appears on the mold face.

d) **Mold Cooling**

The purpose of mold cooling is to control the rate at which heat is removed from the molding. If there is no cooling on the mold then initially the mold will be cool and will heat up due to the heat transfer from the molded parts. This effect can result in varying shrinkage rates. Mold cooling is therefore recommended and the cooling channels should be evenly distributed in the mold. Unbalanced cooling will also have a detrimental effect on the quality and consistency of the product produced.

2.5 WARPAGE OF PLASTIC INJECTION MOLDING PART

Warpage is a distortion where the surfaces of the molded part do not follow the intended shape of the design. Part warpage results from molded-in residual stresses, which, in turn, is caused by differential shrinkage of material in the molded part. If the shrinkage throughout the part is uniform, the molding will not deform or warp, it simply becomes smaller. However, achieving low and uniform shrinkage is a complicated task due to the presence and interaction of many factors such as molecular and fiber orientations, mold cooling, part and mold designs, and process conditions.

Influence of unfilled and filled materials

For fiber reinforced thermoplastics, reinforcing fibers inhibit shrinkage due to their smaller thermal contraction and higher modulus. Therefore, fiber reinforced materials shrink less along the direction in which fibers align (typically the flow direction) compared to the shrinkage in the transverse direction. Similarly, particle-filled thermoplastics shrink less than unfilled grades, but exhibit a more isotropic nature. For non-reinforced materials warpage is generally influenced by wall thickness and mold temperature. If wall thickness and mold temperatures are not optimal the molding will most likely warp.

Different of shrinkage between filled and unfilled materials.

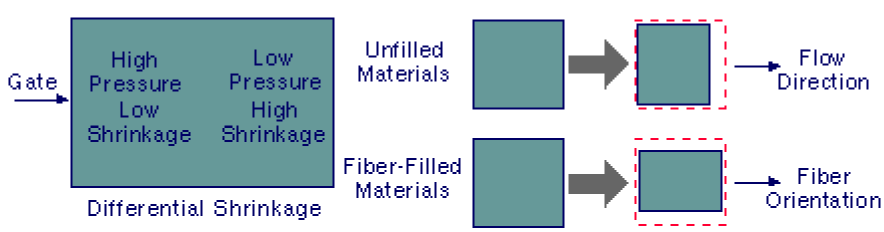

Figure 2.1: Shrinkage Differentials

Source: (http://www.dsm.com/en_US/html/dep/Warpage.htm 24/2/09 Tuesday)

For glass reinforced materials totally different characteristics are evident due to fiber orientation. If a non-reinforced and a fiber reinforced material are compared in the same design it is possible to see contary warpage in the same part.

Unreinforced vs fiber reinforced materials.

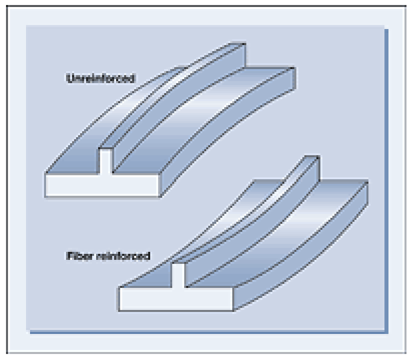

Figure 2.2: Unreinforced Vs Fiber Reinforced

Source: (http://www.dsm.com/en_US/html/dep/Warpage.htm 24/2/09 Tuesday)

Influence of cooling

Non-uniform cooling in the part and asymmetric cooling across the part thickness from the cavity and core can also induce differential shrinkage. The material cools and shrinks inconsistently from the wall to the center, causing warpage after ejection.

Part warpage due to:
(a) non-uniform cooling in the part
(b) asymmetric cooling across the part thickness

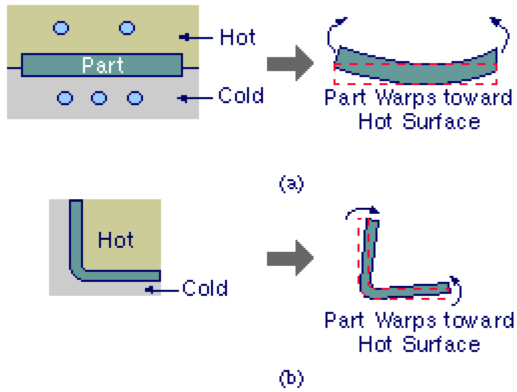

Figure 2.3: Cooling Influence

Source: (http://www.dsm.com/en_US/html/dep/Warpage.htm 24/2/09 Tuesday)

Influence of wall thickness

Shrinkage increases as the wall thickness increases. Differential shrinkage due to non-uniform wall thickness is a major cause of part warpage in unreinforced thermoplastics. More specifically, different cooling rates and crystallization levels generally arise within parts with wall sections of varying thickness. Larger volumetric shrinkage due to the high crystallization level in the slow cooling areas leads to differential shrinkage and thus part warpage.

Diagram of high shrinkage/low cooling vs warped part.

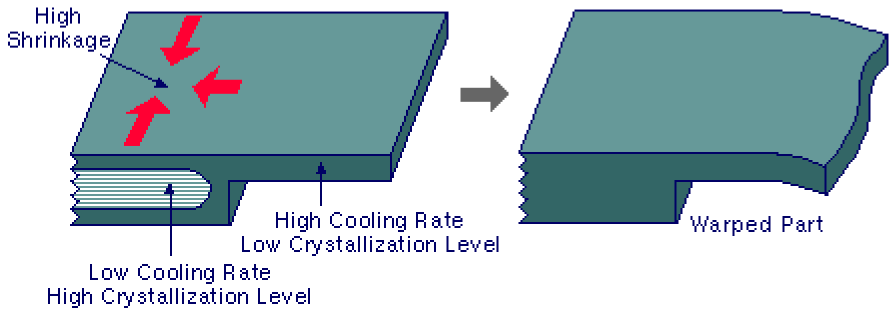

Figure 2.4: High Shrinkage/Low Cooling Vs Warped Part

Source: (http://www.dsm.com/en_US/html/dep/Warpage.htm 24/2/09 Tuesday)

Influence of asymetric geometry

Geometric asymmetry (e.g., a flat plate with a large number of ribs that are aligned in one direction or on one side of the part) will introduce non-uniform cooling and differential shrinkage that can lead to part warpage. The poor cooling of the wall on the ribbed side causes a slower cooling of the material on that one side, which can lead to part warpage.

Poor design vs warped part.

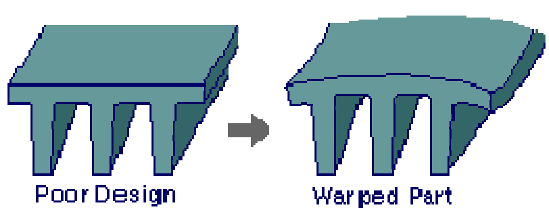

Figure 2.5: Poor Design Vs Warped Part

Source: (http://www.dsm.com/en_US/html/dep/Warpage.htm 24/2/09 Tuesday)

2.6 MOLDFLOW PLASTIC INSIGHTS

Moldflow Plastic Insight products are a complete suite of advanced plastics process simulation tools for predicting and eliminating potential manufacturing problems simulations tools for predicting and eliminating potential manufacturing problems and optimizing part design, mold design and the injection molding process. MPI products simulate the broadest range of manufacturing processes. With MPI, one can simulate the filling, packing and cooling stages of the thermoplastics injection molding process and also predict the resultant fiber orientations and take that into account when predicting part warpage. MPI users can also simulate other complex molding process such as gas assisted injection molding, co-injection molding, injection-compression molding, microcellular molding, reactive molding, and microchip encapsulation. MPI is being employed in both tooling design and simulation of molding. MPI used to simulate mold designs before the tool is actually built. The simulations helps user determine different gate designs and locations, placement of cooling lines, and melt overflows. The Moldflow Plastics Insight suite of software is the world leading product for the in-depth simulations to validate part and mold design. Companies around the world have chosen Moldflow's solution because they offer; Unique, Patented Fusion Technolgy. MPI/Fusion, which is based on Moldflow's patented Dual Domain™ Technology, allows you to analyze CAD solid models of thin-walled parts directly, resulting in a significant decrease in model preparation time. The time savings allow you to analyze more design iterations as well as perform more in depth analyzed.

2.7 RESPONSE SURFACE METHODOLOGY

The RSM is an empirical modeling approach for determining the relationship between various processing parameters and responses with the various desired criteria and searches for the significance of these process parameters in the coupled responses. It is a sequential experimentation strategy for building and optimizing the empirical model. Therefore, RSM is a collection of mathematical and statistical procedures, and is good for the modeling and analysis of problems in which the desired response is affected by several variables. The mathematical model of the desired response to several independent input variables is gained by using the experimental design and applying regression analysis.

The most extensive applications of RSM are in the particular situations where several input variables potentially influence some performance measure or quality characteristic of the process. Thus performance measure or quality characteristic is called the response. The input variables are sometimes called independent variables**,** and they are subject to the control of the scientist or engineer. The field of response surface methodology consists of the experimental strategy for exploring the space of the process or independent variables, empirical statistical modeling to develop an appropriate approximating relationship between the yield and the process variables, and optimization methods for finding the values of the process variables that produce desirable values of the response.

Computationally cost FE model is not suitable for large number of repetitive analyses which are often required in an optimization process. Therefore, in this study, the FE model for warpage is replaced by a simpler and more efficient predictive model created by response surface methodology (RSM). RSM is a model building technique based on statistical design of experiment and least square error fitting.

RSM is a collection of experimental strategies, mathematical methods, and statistical inference that enable an experimenter to make efficient empirical exploration of the system of interest. RSM can be defined as a statistical method that uses quantitative data from appropriate experiments to determine and simultaneously solve multi-variable equations. The work which initially generated interest in the package of techniques was a paper by Box and Wilson in year 1951. To solve such problems with conventional optimization, the RSM has been adopted. With RSM, optimization conditions are first set, and then a response surface is created between design variables and objective functions or constraint conditions (Amago. 19).

This method is now broadly used in many fields, such as chemistry, biology, and manufacturing. RSM can be used to determine the factor levels that will simultaneously satisfy a set of desired specifications and determine the optimum combination of factors that yields a desired response and describes the response near the optimum. Furthermore, it determines how a specific response is affected by changes in the level of the factors over the specified levels of interest it can achieve a quantitative understanding of the system behavior over the region tested. It could also predict product properties throughout the region even at factor combinations not actually run. In general, a second order regression model is developed because of first order models often give lack off fit (Montgomery, D.C. 1997).

In design optimization using RSM, the first task is to determine the optimization model, such as the identification of the interested system measure and the selection of the factors that influence the system measures significantly. To do this, understanding the physical meaning of the problem and some experience are both useful. After this, the important issues are the design of experiments and how to improve the fitting accuracy of the response surface models.RSM designs have the following properties such as predictions always have some degree of uncertainty but there is reasonable prediction throughout the experimental range, uniform prediction error is obtained by using a design the fills out the region of interest, the choice of experimental design is affected by the shape of the experimental region and in most cases, the region is determined by the ranges of the independent variable. Response surface methodology (RSM) is an optimization technique in the field of numerical analysis. For optimization, it uses a function called a response surface. A response surface is a function that approximates a problem with design variables and state quantities, using several analysis or experimental results. In general, design of experiments is used for analysis or experiment point parameter setting, and the least square method is used for function approximation. Response surface methodology is a combination of mathematical and statistical techniques useful for modeling and analyzing the problems in which several independent variables influence a dependent variable or response. The RSM technique attains convergence by repeating numerical and sensitivity analysis until the optimal solution as obtained. For problems with high non-linearity, and